The University of Chicago

THE PROBLEM OF CHANGE IN GREEK SCIENCE

A PART OF A DISSERTATION SUBMITTED
TO THE FACULTY OF THE DIVISION OF
THE HUMANITIES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHILOSOPHY
1931

By
CLIFFORD PIERSON OSBORNE

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A SUMMARY OF THE FIRST THREE CHAPTERS

INTRODUCTION

A curiosity about changes and sequences appeared in the early Greek cults and mythologies and later in the various theogonies and cosomgonies. But theogonies do not constitute a philosophy of science because they attempt to solve the problem of origins and changes by the aid of the poetical imagination rather than by intelligent reflection. Science abandons supernatural agencies acting arbitrarily, and investigates the empirically verifiable factors that are present in the actual situation. By the method of abstraction the early Greek thinkers attempted to pick out the common, identical elements from the various processes of nature, and thus to arrive at a universal first principle to which all changes and diversities could be referred.

CHAPTER I

THE MILESIAN CONCEPTION OF CHANGE

The Milesian philosophy was a daring attempt to present a single principle as underlying all the processes of nature and as supplying the permanent basis for all change.

1. Thales declared water to be the substance from which all things have arisen, but he did not explain the process by which water is changed into its various derivatives.

2. Anaximander selected the Infinite as the fundamental substance. He explained the process of change as a

"separating out" in two directions, the hot and the cold.

3. Anaximines identified the universal substance with air. The manner in which air is transformed into different things he explained as a process of rarefaction and condensation. Like his two predecessors, he held to the theory of hylozoism, namely that changes are internal and that the cosmic matter is in continual self-motion.

4. But the Milesians failed to reconcile the multiplicity of phenomena with the unity of their primitive substances. If the process of change is qualitative, the One is sacrificed to the Many, and if it is quantitative the Many are sacrificed to the One.

CHAPTER II

THE METAPHYSICAL PROBLEM

1. Xenophanes substituted God in place of the Milesian first principle. This God is a homogeneous essence, infinite, eternal, and unchangeable. The theological principle of Xenophanes, then, is to be understood in a pantheistic sense, as a universal physical force and not as a God external to the world. But Xenophanes did not deny all change and movement in the world. In his physical theory he taught that all things arise from earth and water. At this point a striking inconsistency appears in the doctrine of Xenophanes. It is impossible to reconcile an immutable God with a changing world, if God and the world are the same.

2. Heraclitus made eternal motion the central point

in his philosophy, and this principle is embodied in fire. The eternal motion occurs in either one of two directions, the upward or the downward way. The whole cosmic process is characterized by the strife of opposites. But this constant flux takes place in a uniformly recurring series which completes a regular circuit. And so amid all the changes and oppositions there is one constant factor, namely, the law of change itself.

3. In opposition to Heraclitus, who developed the idea of change to the exclusion of a self-identical substance, Parmenides turned to the development of the concept of substance and showed that if this is logically carried out change becomes impossible. The fundamental postulate of Parmenides is that Being excludes all difference and hence admits of no change either of time, place, or quality. What is must be an uncreated, indestructible, finite, spherical, continuum. Hence all coming into Being, passing away, change and alteration are nothing but names which mortals have given to true Being; they are subjective and illusory. In the second part of his poem, however, called The Way of Opinion, Parmenides develops a theory of physics based upon ordinary opinion and intended as the most plausible interpretation of the phenomena of change. The basic assumption of this problematical physics is a dualism of substance.

4. Zeno attempted to defend the Eleatic doctrine by pointing out the contradictions to which the opposed theory

leads. In the case of the first two paradoxes Zeno seems to be trying to refute the assumption that finite spaces and times consist of an infinite number of divisions. His arguments here are fallacious because he implies that a line that is infinitely divisible is an infinitely long line, or that an infinite number of finite moments, make up an infinitely long time, and neither is true. In the last two paradoxes, however, Zeno seems to be directing his arguments against the position that a finite stretch of space or time, consists of a finite number of divisions. In this case his paradoxes are valid. A view of time and space as made up of a finite number of discrete quanta actually does lead to the absurdities that Zeno points out.

5. Melissus attempted to defend the Eleatic doctrine by proving the eternity, the infinity, the unity, and the unchangeableness of Being. He diverges from the theory of Parmenides in ascribing spacial infinity to Being. The reason for this is that there is no Non-being or empty space by which Being can be limited. Melissus maintains that even the pluralists must admit that each of the Many has the same characteristics as the Eleatic One.

CHAPTER III

ATTEMPTS TO SOLVE THIS PROBLEM

Future philosophers were faced with the task of reconciling the Heraclitean-Eleatic conflict. This could be done only by surrendering two attributes of the Eleatic

Being, its unity and spatial immobility.

1. Empedocles asserted the existence of four primitive elements, earth, air, fire and water. These elements are qualitatively unchangeable, but capable of motion and mechanical mixture. All changes are due to combinations and separations of these elements. The causes of change are Love and Strife, and the process itself is made up of four stages.

The theory of mixture and separation assumes the discontinuity of the original matter. But this implies the existence of empty space which Empedocles denied.

2. Anaxagoras postulated an infinite number of qualitative elements. The process of change is a mechanical process of mixture and separation. Like Empedocles, Anaxagoras also assumed a separate cause of motion, namely Nous, which set up a rotatory motion in the original mixture, and thus started the world process.

In postulating as many original elements as there are qualitative determinations in empirical things, the theory of Anaxagoras is uneconomical.

3. Leucippus denied the qualitative determination of the original elements, rejected the theory of the external cause of their motion, and accepted the existence of empty space. His primitive elements, called atoms, differ in shape (A from N), in arrangement (AN from NA), and in position (N from Z). Leucippus explained all changes on the principle of the motions of these atoms in space.

CHAPTER IV

DEMOCRITUS

1. In the hands of Democritus the Atomic theory became more elaborated and systematized. He took over the main outline of this theory from Leucippus, namely, the conception of an infinite number of indivisible particles moving in an infinite void. He calls the ultimate particles "atoms", as did Leucippus, and reinforces Leucippus' distinction between the void and absolute non-existence.[1] The basic principle of atomism is the same in all cases, that of an infinite number of homogeneous elements without qualitative distinction, moving in a void. It was thus devised as a theory that would admit both permanence and change as real.

Democritus found the element of permanence in the structure of the atom itself, and this represents the changeless character of reality. The internal characteristic of the atom is its physical being or stuff. The Democritan conception of the stuff of the atom corresponds to the modern physicist's conception of mass as the central reality of the thing. But the atoms of Democritus have the same density, and differences in weight must be due entirely to differences

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[1]Arist. Phys. I,5.188a; Diels,A.45.

in magnitude. The modern physicist avoids this difficulty by defining mass in terms of inertia, that is, the persistence of matter in its state of either rest or motion, and this takes account both of the fact of volume and of density.

But the characters which distinguish one atom from the other cannot be stated in terms of the stuff or inside of the atom. This must be approached from the outside, and so Democritus, like Leucippus, introduced the void as a means of distinguishing between the different atoms, and expressed these differences in terms of shape, position, and arrangement. These quantitative differences in the elemental substances were deemed sufficient to account for the endless variety of complex objects.

But there was another reason for the introduction of empty space, and that was to account for change. If reality consists entirely of changeless particles of stuff, Becoming is impossible, as Leucippus had noted. There must be a void in which the atoms can move. The physical character of the atoms, then, accounts for the fact of permanence, and their motion in the void accounts for the fact of change. Since both the atoms and space possess fixed qualities, the principle of Being is satisfied, and since the atoms can change their spatial relations the principle of Becoming is satisfied. All change arises from the movement of unchangeable particles in the void. This gives both the change of Heraclitus and the permanence of Parmenides.

Thus far the theory of Democritus is essentially the same as that of Leucippus. But at this point we may note three great innovations which Democritus introduced into the atomic theory. (1) He was the first of the Atomists to proclaim the principle that "nothing is created out of the non-existent, or is destroyed into the non-existent."[2] In this statement he shows his agreement with the fundamental postulate of the Parmenidean Monism--the eternity and permanence of Being. (2) He maintained that the universe was infinite because it was not created by anyone.[3] This is to be understood not as a spatial infinity, as with Leucippus, but as a temporal infinity. (3) He placed "necessity" in the forefront of his system. "By necessity are foreordained all things that were and are to come."[4] Leucippus had already applied this notion to the original motion of the atoms, but Democritus gives it a universal application. In this way he gets rid of the external causes, such as the Love and Hate of Empedocles, and the Nous of Anaxagoras, discards any possibility of design, and regards the universe as a mechanical contrivance controlled by its own inner nature. With the introduction of the idea of Necessity atomism came into its own as a pure scientific theory. These three innovations of Democritus furnished a metaphysical basis for a true scientific account of the world.

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[2] D.L.ix.44; Diels,A.1.
[3] Plut. Strom.7; Diels,A.39.
[4] Loc.cit.

2. As a result of the presuppositions of atomism, all of the qualities of things depend upon the size, shape and spatial relations of the atoms, and all changes are due to altered combinations of atoms. An object originates when a complex of atoms is formed, and perishes when the complex is dissolved. All changes are mechanical and depend upon the quantitative relations of the atoms.

What is the cause of this motion that is responsible for the combination and separation of atoms? The common assumption is that the Atomists regarded weight as the cause of the motions of the atoms, and this would mean that their original motion was in one direction, downward.[5] Epicurus and the later Atomists did, in fact, hold this view, but it is doubtful whether this is true in the case of Democritus. Bailey,[6] after an exhaustive review of the evidence, concludes that Democritus did not assign weight as a primary property of the atoms and make it a cause of their motion. He maintains that in the Democritean theory size and shape are the only primary properties of the atoms, and that "though Democritus spoke of heavier and lighter atoms, he did not attribute absolute weight to them.....but regarded weight as a derivative property from size." Moreover, according to Bailey, this

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[5] This interpretation is still championed by Zeller, II,241. The first to oppose this view was A. Brieger, Die Urbewegung der Atome; Halle, 1884.

[6] Greek Atomists and Epicurus, p.131ff.

weight did not act when the atoms were free in the void; it acts only in the cosmic whirl, where it resists the movement of the whirl. The original motion, then, was not in one direction downward, but in all directions.[7] And the cause of this motion was not weight, but "necessity".[8] This means that motion is inherent in the very nature of the atoms, and like the atoms themselves, is eternal.[9]

The atoms, then, move according to the law of their own being. Because of their movements in all directions, they come into collision with one another. Due to the variety in their shapes they thus grasp and fit into one another and, as a result of this interlacing, aggregates are formed. But these aggregates do not form new single existences, because two or more things can never become one.[10] New combinations, then, are purely mechanical, and a seeming mixture is only a juxtaposition of atoms. The aggregates develop motions of their own because of the combined motions of the separate atoms in the aggregates. If the motion of any particular aggregate appears in the form of a whirl, this leads to the formulation of a world.

Since some of the aggregates acquire whirling motions and some do not we are confronted with the question of the cause of the whirl. Here there are two seemingly conflicting

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[7] Arist. De Caelo.I,10.279; Diels,A.37.
[8] Arist. De Gen. Animal.V,8.789b; Diels,A.66.
[9] Hipp. Ref.i.13; Diels,A.40.
[10] Arist. De Caelo.I,10.279; Diels,A.37.

points of view. Diogenes maintains that Democritus attributed the cause of the whirl to "necessity."[11] This would be in conformity with Democritus' fundamental principle with regard to the cause of the original motions of the atoms. But Aristotle, on the other hand, claims that the Atomists held the opinion that the whirl was produced automatically, that is,by chance.[12] It is not very difficult, however, to reconcile the notion of necessity with that of chance, in this case. The whirl is necessary in the sense that it is not a causeless event, but is the "inevitable outcome of natural processes." But the whirl is also a chance occurrence in the sense that it is "undesigned and unpredictable." If we consider a chance occurrence as one whose causes are indefinite and unascertainable, the notion of chance is not incompatible with that of necessity.

According to Aristotle[13] the whirl was conceived as analogous to an eddy of water, that is, as horizontal and not vertical. The principle of combination by which atoms come together in this whirl is the attraction of like for like; the larger (heavier) atoms join with the larger and the smaller (lighter) with the smaller. Because of their bulk and resistance, the larger atoms make their way toward the center of the whirl, just like sticks thrown into an eddy of water.

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[11] ix.45; Diels,A.1.
[12] Phys.II,4.196a; Diels,A.69.
[13] De Caelo,II,13.295a.

The smaller atoms are thus pushed out into the outer part of the vortex which is thinned and rarefied. The heavy mass in the center becomes more and more compact and forms the earth. The outer part of the vortex attracts other bodies from the outer universe during the whirl and these are united in aggregates to form the heavenly bodies.[14] In this same way innumerable worlds are formed. Since these worlds all had a beginning they are also subject to destruction, and are annihilated when two of them come together and the smaller is crushed by the larger.[15]

3. Atomism reduces all phenomena to a mechanics of atoms. All qualitative changes, then, are to be referred back to quantitative relations of the atoms, their arrangements and their motions. The true reality consists of atoms moving in the void, and, according to Democritus, this is comprehended by thought. The whole phenomenal realm of changes, however, must be considered as a derivative of the true reality, and this is comprehended by sensation. Democritus had to account for the changing world, so he put this in the realm of sense. The sensuous experiences are perturbations of the soul; the only reality is the atom which has motion, but which does not change. Democritus distinguished between states of consciousness as qualities and changes taking place in nature. He took all of the sense qualities out

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[14] There is no separate account of Democritus' cosmogony. The account referring to Leucippus, given in Diogenes ix,31,2 holds also for Democritus.

[15] Hipp. Ref. 1.13; Diels, A.40.

of the world and found reality in the atom and in motion. In order to throw more light on this question we shall have to consider, briefly, the Democritan theory of sensation and thought.

The soul and the mind, for Democritus, are identical inasmuch as they both have the same atomic constitution.[16] The soul atoms, however, are distributed over the whole body while the thought atoms are concentrated at one place in the body, unmixed. The former is the seat of sensation, and the latter of thought. The identification of soul and mind thus leads to a similar identification of sensation and thought.

Sensation is caused by changes in the soul atoms produced by external impressions.[17] Emanations from the object penetrate into the body through the sense organs and disturb the soul atoms; the result is sensation. This is a purely mechanical theory which regards sensations as produced only by the contact of emanations with the sense organs. Democritus represented all sensations as various kinds of touch.[18] The theory behind this is the attraction of like for like. In order to make perception possible the material constitution of the object must correspond to that of the sense organ. Sensation occurs only when the motions of the object come in contact with similar motions from the soul atoms of the organ.

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[16] Arist. De Anima.I,2.404a,29.
[17] Theophr. De Sensu,49; Diels,A.135.
[18] Arist. De Sensu,4.442a,29; Diels,A.119.

Thought also, like perception, is caused by a change or alteration in the body produced by external impressions.[19] Sensation and thought are the same in the sense that they have the same origin. The effluences that are too fine to disturb the soul atoms pass on to the mind and cause thought. In sensation it is the coarse emanations that are active, while in thought it is the very fine emanations. Thought, then, is really a particular kind of sensation. The two processes are analogous and both can be reduced to a purely material contact.

But sensation and thought do not have the same epistemological value for Democritus. Although the faculties of perception and thought are the same, there is a distinction between them from the standpoint of the theory of knowledge. Sextus[20] maintains that Democritus said there were two kinds of knowledge, that through the senses and that through the mind; the latter is "legitimate" and the former "bastard." The inference is that the "legitimate" knowledge is of atoms and the void, and that the bastard knowledge is of the perceived qualities. The mind, which deals with realities, gives true knowledge; the senses, which deal with the changeable phenomena, give obscure knowledge. The only real knowledge is knowledge of atoms and the void, and this is reached by thought. Since atoms, and the void are both imperceptible

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[19] Aetius.iv.8.5; Diels (Leucippus),A.30.
[20] vii.138,9; Diels,B.11.

to the senses, the senses cannot give true knowledge of the nature of things. This skepticism, however, is limited to sensible perdeption; it does not apply to true thought.

This same idea is reinforced by a quotation attributed to Democritus himself. According to Diogenes, Democritus said, "sweet is by convention and bitter by convention, hot, cold, and color by convention; in truth are atoms and the void."[21] Here we have an introduction of the distinction between primary and secondary qualities, which played such an important role in early modern philosophy. Size, form, density, and hardness are true properties of things; the perceived qualities on the other hand, such as color, sound, smell and taste, are conventional, that is, subjective; they are not actual qualities in things. At this point Democritus shows the influence of the Protagorean theory of relativity. Protagoras, however, had considered all being as relative and subjective, while Democritus retains the objective world and limits the subjectivity to the secondary qualities.

The world of becoming and change, then, has only a relative reality. The world of being, i.e., atoms and space, is the absolute reality. This means that nature is different from what it appears to be. The whole realm of qualitative change lies outside of the true essence of things. Qualitative differences are only apparent due to our sense impressions of various combinations. True reality is reached

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[21] D.L.ix.72; Diels,B.117.

only by thought.

4. In defining the object of scientific knowledge as that which is capable of quantitative determination, the theory of Democritus is in close accord with modern science. But the striking difference between the two is that Democritus applied his quantitative principle only to the realm of Being, while modern science applies it to the realm of Becoming or change in nature. The quantitative theory tries to reconcile permanence and change by finding some constant factor that persists throughout all change. In the case of Democritus, however, this unchanging factor was limited to a permanence of substance or Being. The fact that he could not apply mathematical principles to motion prevented him from bringing constancy into the field of change in terms of a law of change. He did not present nature as governed by law but by chance. His description of natural processes is that of a concourse of atoms bombarding each other and conflicting according to the laws of their own nature. Inasmuch as these motions of the atoms are unascertainable and unpredictable for human reason, they are chance occurrences. There is no method of prediction or control in this theory. The modern scientist, on the other hand, by applying mathematical principles to motion, can express the process of change in terms of laws.

Democritus succeeds in reconciling the opposition between permanence and change in his own fashion. Empty space makes possible various shapes and motions, but the

permanence of the elements is unaffected. To accomplish his purpose, however, Democritus has to sacrifice a great part of the universe. All of those characters which cannot be stated in quantitative terms must be considered as "perturbations of the soul," and hence as abnormalities. The values of experience, then, disappear. A large part of the contents of objects, namely, the secondary qualities, is discarded as having no cosmical importance. These qualities, according to Democritus, are known only by sensation, and sensation does not express the true meaning of reality.

In contrast to this, modern thought has given a tremendous sweep to consciousness as a habitat for the meaning of the world. Consciousness serves as a locus where the contents of objects can be placed without making them "confusions" or "obscurities". In modern thought states of consciousness have become contents, and this has proved of great advantage for the advance of science. If the secondary qualities are put in consciousness, then science can go ahead with a quantitative statement of the universe. This problem, however, did not concern the ancient world; the contents had to be left in the object to have any value at all. Hence, if the world is made up of a set of motions, as in the Democritean statement, then the secondary qualities have to be discarded because there is no place to put them. The "perturbations of the soul" is not a satisfactory habitat for the meaning of the universe. It is true that the Democritean doctrine has

given us the modern mechanical universe, but before his theory could have value for modern science, it had to be supplemented by the idea of consciousness as an adequate repository for the qualities of objects.

CHAPTER V

PLATO

1. Plato's conception of change is based in large measure, upon his Theory of Ideas. This theory had its origin in the opposition between Socrates and the Sophists. The homo mensura formula of Protagoras had destroyed all objective standards of truth and goodness and threatened the foundations of morality. Hand in hand with a relativist theory of knowledge, based on perception, went a virtue of custom based on convention and exposed to the insecurity of change and opinion. Socrates saw the inadequacy of the Sophistic theory for a true science of ethics. In conformity to his fundamental principle that virtue is knowledge, he felt that true virtue must rest on true knowledge. So he was faced with the necessity of transcending the relativist doctrine in order to get a theory of knowledge that would not be subject to the variations of individual opinion.

True knowledge, according to Socrates, is concerned with the universal rather than with the particular, and must be reached by a study of concepts. A concept is formed by abstracting the common element from a variety of things. The conceptual method is a method of induction which consists in finding the universal in a given number of examples. But

this universal belongs to the world of thought and not to the world of sense. Hence reason, and not perception, becomes the organ of knowledge. In introducting the abstract universal into philosophy, Socrates took an important step in advance of his predecessors.

Plato developed the Socratic universal into a metaphysical and epistemological doctrine known as the Theory of Ideas. He transformed the concepts into metaphysical substances called forms or Ideas. These forms are not ideas in the mind, but real independent existences. The Ideas are universals, types, forms, patterns, eternal, immaterial, self-subsistent, real, ousia, essentia, objective. They are prior to and independent of individual things. The particular objects of perception are imperfect copies of these eternal forms. There are as many Ideas as there are general predicates or classes of things. The realm of Ideas constitutes an interrelated unity; the Ideas are arranged in the order of a hierarchy, and subsumed under the highest Idea, the Idea of the Good. The Ideas represent a Parmenidean reality that is opposed to change; they are underived, imperishable, and unchangeable.

In addition to this realm of Ideas is the sensible world, the whole content of which is subject to change. For Plato, as for Heraclitus, everything in this world is in a state of incessant transformation. This is a realm of material things in which every individual object possesses its

own qualities in combination with their opposites.

With this dualism Plato was able to combine the theories of his predecessors. On the one hand is a world of incorporeal forms which expresses true reality, and on the other, a world of material things which expresses only apparent reality. The former is permanent and immutable, the realm of Being; the latter is ephemeral and changing, the realm of Becoming. The first is the object of reason and the second the object of sense perception. The one gives true knowledge, the other mere opinion. The world of Being makes possible the conceptual knowledge of Socrates, and the permanence of Parmenides; the world of Becoming makes possible the relativism of Protagoras and the flux of Heraclitus.

2. According to the Platonic theory material objects are copies or shadows of the Ideas, that is, imitations of the ideal patterns.[1] The relationship between the two worlds, then, is to be conceived as one of similarity. But things are copied from and similar to Ideas only in so far as they participate in them; copying is an imperfect participation in Ideas. Phenomenal objects never take on the complete reality of the Ideas, but merely approach it, and whatever reality the world of Becoming acquires is due to this fact of participation.[2] Just as the subject only reveals itself by its attributes, Becoming exists only because of participation in

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[1] Rep., 596ff.
[2] Phaedo, 100C; Parmen., 129A.

the veritable Being of the Ideas. Things which have the same predicates are copies of the same universal, and things owe their similarity to one another because of their participation in the same universals.

All qualitative change, then, is to be explained by this notion of participation. When Ideas enter into or depart from objects, those objects undergo changes in quality.[3] Not only is the process of change represented as a coming and going of Ideas, but Ideas are also held to be the causes of changes in the phenomenal world.

> If anyone should tell me why a thing is beautiful, ...I dismiss all other reasons, ... and confine myself to this, that nothing else causes it to be beautiful, except either the presence or communication of that abstract beauty, by whatever means and in whatever way communicated.[4]

Everything has the Idea as cause of its existence and of the particular qualities that belong to it. By this method, Plato sought to overcome the limitations of the Nous theory of Anaxagoras.

This conception of the Ideas as the causes of phenomenal changes is reinforced by the doctrine given in the Sophist. There we find that the Ideas can be the causes of motion and change in the sensible world only on the condition that they themselves have motion and life, and act as powers. "Anything which possesses any sort of power to affect another has real existence, ... and I hold that the definition of

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[3] Phaedo, 100D.
[4] Loc. cit.

Being is simply power" (247D). Ideas, then, are not merely archetypes but energetic powers, and act as the efficient causes of change.[5]

Not only does Plato attribute efficient power to the Ideas, but also designing reason.[6] Here we have a teleological explanation of nature by which changes become tendencies to realize ideal purposes, and with this thought the idealism of Plato is brought in sharpest contrast with the pure mechanism of Democritus. Becoming, with Plato, means a tendency to reproduce and manifest the Idea. This conception of purpose applies to the whole realm of Ideas but particularly to the Idea of the Good in which the hierarchy of forms has its culmination. In the Republic (508ff.) the Good is pictured as ultimate cause of Being and of Knowledge; it is the sun of the intelligible world. "The good may be said to be not only the author of knowledge in all things known, but of their Being and essence, and yet the Good is not essence, but far exceeds essence in dignity and power.[7] The Idea of the Good, then, represents the highest end of all reality.

In addition to the principle of purpose, Plato introduced a second principle to explain the mutability of things. Since the Ideas can only be the cause of perfection,

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[5] This thought is, of course, based upon the assumption that Plato's criticism of the "friends of forms" does not apply to his own theory. See Taylor, Plato, p. 385.

[6] Phileb.,54C; 28E.

[7] Rep.,509C.

the phenomenal world would be perfect if it consisted only of Ideas. But the sense world also contains imperfections and the principle by which these are accounted for is the Platonic matter or Non-being. This is the matrix or "receptacle" in which Becoming takes place, and appears as a third concept along with Ideas and sensible phenomena.[8] The Platonic matter is the permanent factor which underlies the whole process of change. In the Philebus (23) this universal substratum is called the Unlimited. We may consider it as the unformed something, without quality, upon which the Ideas impress themselves to form sensible things. This Platonic matter is not material substance, but empty space.[9] This empty space is the condition of separation, division, and change.

The appearance of the sensible world, then, is due to the action of Ideas on empty space. The sense world partakes of both Being and Non-being. It owes its reality and perfection to the Ideas, and its diversities and imperfections to empty space. So in addition to the purposeful causality of the Ideas, and especially of the Idea of the Good, in the determination of phenomena, there also appears a second kind of causality--the blindly acting causality of the Platonic matter. The former is a causality of reason; the latter a causality of necessity. Necessity tends to resist the

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[8] Timaeus, 48E.

[9] See Zeller, Plato and the Older Academy, p. 312; also Taylor, Plato, p. 456.

activity of the Ideas in sensible things. The ideal part of the sensible world is determined by reason, the material part by necessity. Reason represents the purposeful activity of the Ideas; necessity, the recalcitrant activity of empty space.

3. Reality, for Plato, lies in the realm of universals, which represents a permanent, static field without relation to any process of change. Since it is in the field of mathematics that these universals first appear, Plato's Idealism is a mathematical theory. Mathematical forms and figures, like the Platonic Ideas, have logical location outside the field of experience. But they have a universal meaning, although we never meet with perfect examples of them in the world of sense.

Plato substituted a mathematical world of geometric forms in place of the Democritan world of physical objects. Instead of a collection of moving, physical atoms, reality now appears as a system of logical or mathematical forms. Plato's chief contention is that the real is Being and is rational rather than physical. The Pythagorean influence upon Plato at this point was very strong. Pythagoras had expressed the numerical and mathematical nature of the universe by saying that the real is number.

The ontological importance of mathematics in Plato's system is best brought out in the Philebus (23Cff.). Here there is a fourfold division of the actual; the Infinite, the

Limit, the Mixture and the cause of the Mixture. The Infinite is to be understood as the Platonic matter or empty space; the Limit, as the mathematical limitation and formation of that space; the Mixture, as the world of sense that is formed by the combination of these two; and the cause of the Mixture, as the Idea of the Good. The Limit includes everything that is capable of exact numerical determination. So Plato interposed between the Ideas and the sensible things an intermediate class of mathematicals. "Mathematical forms are the links by means of which the Ideas shape space teleologically into the sense world."

But mathematics also has a very important epistemological significance in the Platonic system, as a method for the attainment of pure knowledge. According to Plato's doctrine the object of pure scientific knowledge is something that may be indicated by the world of sense, but actually belongs to a higher degree of reality. The function of a true scientific method, then, is to enable us to escape from Becoming and perishing and all other forms of change, and to grasp the universal and the permanent. The study of change is not pure science, because it ignores the structure and permanence of true reality. The process of change lies outside of the true reality with which knowledge deals. Our attention is to be diverted from the perception of phenomena to a contemplation of forms, from change to rest. True science leads us beyond the ephemeral copies to the identification of

of the universals themselves and their mutual relations.

This point is very well illustrated in Plato's memory theory of knowledge. According to this theory knowledge is a recollection of those things which the soul once beheld when in company with the gods.[10] Sensible things serve as suggestions or reminders of the ideal forms which the soul gazed upon before its incorporation with the body. Now it is in the field of mathematics that the strongest suggestions of the supersensible forms is acquired. The slave in the Meno (80), with some help from Socrates, could perform certain mathematical operations with considerable skill, although he had had no previous training in that line. By this illustration Plato shows that mathematical relations are not present in corporeal reality and that sense-perception offers only the occasion for the recollection of such relations.

We can now readily understand the important role that mathematics played in Plato's scientific method. It is in the field of mathematics that the universals first appear, so that if true scientific knowledge is a knowledge of universals, mathematics becomes an indispensible means of attaining such knowledge. Mathematics is a propadeutic to philosophy; hence the significance of the academic inscription "Only mathematicians need enter here." The educational scheme of the Republic (525ff.) comprises the following stpps; arithmetic,

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[10] Phaedo, 72E; Phaedrus, 249.

plane geometry, solid geometry, astronomy and harmonics, and dialectic. By means of the hypothetical abstractions of mathematics the philosopher is helped to rise above the changing phenomena and to attain a vision of the true reality represented by the Ideas. Mathematics, then, is the highest preparation for true science. But it is still only a preparation and must be carefully distinguished from dialectic. Both deal with realities, but in different spheres of the ideal world. The first division of the line in the Republic (510ff.) gives the intelligible world and the sensible world, with the corresponding epistemological distinction of knowledge (νόησις) and opinion (δόξα). But within the former there is a further distinction between reason (ἐπιστήμη) and understanding (διάνοια). Mathematics answers to the latter and dialectic to the former. Mathematics depends upon sensible aids such as geometric figures and angles, and hence does not allow the mind to rise above hypotheses. In dialectic, however, hypotheses are used only as points of departure to enable the soul to soar to first principles, namely, Ideas.

4. Although Plato always remained true to his metaphysical principle that the sense world cannot be the object of true knowledge, he does condescend, in the Timaeus, to develop a theory of natural science based on Becoming. This is to be considered as a hypothetical physics rather than an exact science. He still maintains his distinction between

eternal Being and temporal Becoming, and makes it plain that there can never be a true knowledge of Becoming, but only a probable knowledge (29B).

According to the Timaeus, the demiurge, because of his goodness, fashioned the visible world which is temporal, after the eternal model, namely, the forms (29ff.). Plato here shows his opposition to the Democritean theory of a plurality of worlds, arising wherever a vortex is formed, by asserting that the demiurge creates only one most perfect world. The perfection of the world implies intelligence and hence a soul is required (30B). The first creation of the demiurge, then, was the world soul, which is the source of all motion. This soul is composed of two elements, the unitary (Idea) which is always the same, and the divisible (space) which changes. God mixed them into a third substance and then combined all three into a whole. He then divided this whole according to the intervals of a musical scale, and by a longitudinal bisection formed the circles of the Same and the Other, that is, the circles of the sidereal equator and the ecliptic. The latter was again subdivided into six concentric circles in which the sun and the planets have their orbits (34-36).

These two circles form the structure of the whole universe. They were placed obliquely to each other and the circle of the Same was made to revolve to the right and the circle of the Other to the left. The source of the motion

of the circles is the soul turning within itself (34B, 36E), and this imparts motion to the whole universe. The soul is something that can move itself as well as other things and hence it is the ruling principle of the world. There is a striking parallel here with the theory of motion as given in the Laws. In his attempt to refute Atheism in the Tenth Book of the Laws, Plato begins with an analysis of the word motion. Ten different kinds of motion are mentioned, culminating in the last two, about which the discussion centers, causally communicated motion and spontaneous motion. Causally communicated motion is a motion that can move something else, but cannot move itself. Spontaneous motion is one that can move itself as well as other things. Physical things do not have the power of spontaneous motion, this property belongs only to that which has life, namely, the soul. The soul, then, is the source and principle of all cosmic motion because it is a "movement that can move itself."[11]

Resuming the account of the cosmology of the Timaeus, we find that the next task of the demiurge was the construction of the body of the world. As we have seen, the receptable or matrix out of which the visible world was formed, is empty space. The first step in introducing order into this chaos was the geometrical construction of bodies. The two ultimate "elements" of the Timaeus are the "half-square", formed by bisecting a square diagonally, and the "half-triangle", formed

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[11] Laws X, 892-896.

by bisecting an equilateral triangle by a perpendicular. These two triangles can be grouped to form various types of planes out of which bodies are formed. From the first kind of triangle is formed the cube, and from the second kind are formed the tetrahedron, the octahedron, and the icosahedron; these are the four regular solids that can be inscribed in a sphere. These four solids correspond to the four Empedoclean roots. The cube is the fundamental form of earth; the tetrahedron, of fire; the octahedron, of air; and the icosahedron, of water (53 ff.). From this account we can see that the constituents which compose the body of the world are formed by mathematical limitations of empty space, and this again corresponds to the doctrine of the Philebus, viz., that the Limit consists of the mathematicals by which empty space is fashioned to represent the Ideas. The primary elements are not bodies, as with Democritus, but surfaces. Matter is not corporeal, but geometric, and bodies are both limited by and compounded out of planes. Thus Plato reduced physics to applied geometry as did Descartes.

The elemental bodies differ from one another in magnitude because of the differences in the number of triangles which each contains. There are also differences in magnitude within each particular element owing to the difference in the sizes of the triangles. It is the mixture of these quantitatively different elements that accounts for the multiplicity of phenomena and for the fact of change (57C). The revolution

of the universe presses together all the bodies contained in it, and will not allow any place to be left void (58A). The smaller particles are then thrust into the interstices of the larger and, due to the pressure, are cut up into small pieces. These parts must either unite with the larger element or escape to their own kind (57A). Thus a perpetual motion of the elements is maintained because of their diversity (58C).

5. Plato's metaphysical theory is inadequate to explain the derivation of phenomena. They cannot be derived from something that is not an Idea because the Ideas alone have reality, and there can be no other real principle to account for finite existence. Nor can phenomena be derived from Ideas because there is "nothing to determine Ideas to break up their unity and to combine with Non-being to form phenomena." Indeed, it is hard to see how phenomena can have any existence at all if the sole reality is in the Ideas.

This dualism of the Idea and the phenomenon makes it impossible for Plato to Bring permanence and change together. Permanence remains in a field by itself without ever invading the field of change. This is due to the sharp line of distinction that Plato draws between the realm of Being and that of Becoming. The former is to be identified with permanence, and the latter with change. On the one hand we have a world of reality which is static and known only by reason, and on the other hand a world of appearance which is changing and known only by observation. Plato gives no consistent

interpretation of the relationship between these two fields. The only reality is in the universal and this represents a static field without relation to a process that is going on. The process of change lies outside of the true reality with which knowledge deals. The nature of reality cannot be expressed in terms of the change, nor can the nature of the change be expressed in terms of reality; the two fields are opposed. Plato nowhere explains how change springs from the reality of the Idea, or how the Idea developes out of the process of change; there is no functional relationship between the form and the change. The relationship that Plato suggests, namely that of participation, is entirely inadequate, because it fails to explain how things participate in Ideas, or how Ideas bring about changes in the tangible world. Change is rather to be considered as a "departure" from the fixity that is found in the Idea. That Plato himself recognized the inadequacy of the "participation" theory, may be judged from the criticisms that he directs against this doctrine in the Parmenides.

Plato emphasized the value of mathematics as a scientific tool, and this has been the source of many great achievements in science. But Plato's mathematical method was limited in its scope and could be applied only to uniform and static situations. The function of mathematics, for Plato, was to enable us to rise above the fleeting world of sense and to ascend to the realm of fixed and abiding

universals. The limitation of such an employment of mathematics is that it cannot be applied to the world of change so as to give a statement of changes as they are going on. The fact that there was no infinitesimal calculus during his time prevented Plato from carrying his mathematical method over into the field of change and measuring changes as they occur. A mathematical technique which can apply only to static situations cannot bring reality into change in the form of mathematical laws.

Modern science has employed the mathematical method with great success, but it has broadened the scope of its application to include also the world of Becoming. We now have a mathematical apparatus that enables us to take care of the very thing that made Plato think that the world of experience is a world of unreality. By means of the calculus, modern science can get a mathematical statement of change itself, and hence can bring reality into change in the form of mathematical laws. This makes possible the prediction and control of events. Plato, however, had no mathematical technique for dealing with the world of experience and hence regarded that world as a world of unreality.

CHAPTER VI

ARISTOTLE

1. The attempts of the Pre-Socratic philosophers to solve the problem of change did not satisfy Aristotle. He objected to the earlier philosophy because it was dominated by the idea of matter and because it took no account of final causes. The Milesian school according to Aristotle, had overlooked the cause of movement, and had arbitrarily selected one simple body as the first principle of all things without inquiring how it can be transformed into its various productions.[1] Heraclitus had generalized too broadly and from the changes in a minority of sensible things had inferred the continual flux of the entire universe. Moreover, he overlooked the substratum of change.[2] The theory of Empedocles, which attempted to reduce all changes to a combination and separation of four qualitatively determined elements, failed to give any satisfactory explanation of qualitative change.[3] Aristotle directs a similar criticism against the Atomists. Ultimate particles which are without quality and which cannot interact with one another cannot account for the rich diversity

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[1] *Met.* A, 8. 988b, 26.
[2] *Met.* Γ, 5. 1010a, 15.
[3] *Met.* A, 8. 989a, 22-30.

of qualitative changes.[4] The same objection applies also to Anaxagoras. The immutability of the original elements is inconsistent with the empirical fact of change.[5] As for the Eleatics, they did not make any attempt to explain multiplicity and change, but simply passed them off as illusions. Aristotle regards the theories of Xenophanes and Melissus as too naive for serious consideration. As proof of the inadequacy of the Eleatic theory to account for empirical events, he cites the fact that Parmenides was forced to depart from his fundamental proposition, to follow the observed facts, and to admit that according to our sensations things are multiple and changing.[6] But Aristotle particularly attacks the theory of Zeno, which, he thinks, is based upon the fallacious assumption that space and time are made up of discrete units.[7]

Aristotle, however, is more directly interested in the limitations of the Socratic-Platonic conceptual philosophy. In fact, the Aristotelian metaphysics had its origin in the attempt to transform the Platonic philosophy into a theory that would account for phenomena and changes. Aristotle agrees with Plato that sensible things are changeable and that the only true object of knowledge is the universal. But

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[4] Gen. et Corr. I,8.326a.
[5] Ibid. I,1.
[6] Met.A,5.986b,10ff.
[7] Phys.VI,9.239b,10.

he objects to Plato's assumption that these Ideas have substantial existence beyond the world of phenomena. Such a theory, he thinks, leaves too broad a gap between the Idea and the thing, and by assigning reality only to the Idea, fails entirely to account for the phenomenal world.[8] The forms do not contribute anything to the sensible world; they cannot be the cause either of movement or change, because they do not have motive power. Aristotle's whole objection to the Platonic theory centers about the fact that Plato fails to explain how Ideas can be the causes of the phenomenal world. The reason for this failure, he thinks, is that the world of Ideas is divorced from the world of sense experience.

3. Aristotle still wished to retain the Ideas in order to explain Becoming, but for this very reason he felt it necessary to reject their transcendence. He acknowledges that the universal represents the truly actual, the sole object of knowledge, and the permanent basis for change.[9] But the Ideas must be understood in such a way as to explain the origin of phenomena. Such an explanation is possible, according to Aristotle, if the Ideas are transferred from the "world beyond the heavens," and placed in individual things as their true essence. The universal is the true actuality, but it exists only in the particular. For Aristotle the sense world and the ideal world are identical; there is no separation of the universal from the thing

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[8] Met.A,9.990b,ff.
[9] Met.B,4.999a,28ff.

itself.[10] The forms exist only by being realized in individual things, and individual things exist only by manifesting the forms.

The function of true science, according to Aristotle, is to discover the essential character of the object. This essential character is recognized in terms of the form or the species. True science, then, must transcend the accidental and determine existent reality by the general conception. It is only by means of the essential character that we can get to the individual things. But, on the other hand, the forms have reality only when they appear in individual objects; the universal is recognized only in the particular. So scientific knowledge is also partly directed toward individual things in so far as particulars are instances of universals.

Individual objects have a material aspect and a formal aspect, and it is these two factors, that play a leading part in Aristotle's metaphysics. It is the form alone that can be the true object of knowledge and that represents the permanent amid change. All origination implies a form which itself did not originate.[11] But in addition to form there is also matter. In the Aristotelain system matter is not the Platonic Non-being or empty space, but a corporeal substratum--something that has the capacity for change.[12] Matter is the completely

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[10] Met.M,9.1086b,3.
[11] Met.B,4.999b,5.
[12] Met.H,1.1042a,32; 3.1043b,14.

undetermined which receives the impressions of the forms. All phenomenal objects are to be considered as formed matter.

Along with this antithesis of matter and form there is a corresponding antithesis of potentiality and actuality. Matter is the potentiality of that which becomes actual only upon the realization of its form. The essential nature of a thing is only potential in the matter, but it becomes actual by means of the form.[13] Pure matter would be matter which has not yet become anything, but, according to Aristotle, such matter doesn't exist except as potentiality. Pure form, on the other hand, is complete actuality or realization. Between these two there can be an infinite number of degrees. There is no opposition between these two, however, and the same thing can be regarded as matter or as form according to whether we consider it from the standpoint of potentiality or of actuality.[14] Matter is the possibility of Becoming and form is the active condition of Becoming. Matter is the substratum which underlies everything but it may become anything according to the form that is impressed upon it. This implies that the form is present in the matter ideally and potentially, though not actually.

All changes, then, are to be explained as matter taking on form.[15] In the processes of nature the essence of things passes from possibility into actuality. Becoming is a

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[13] De An. II, 1. 412a, 6.
[14] Met. H, 6. 1045b, 18.
[15] Phys. III, 1. 201a, 10; b, 4.

process of realization or actualization. This is Aristotle's solution of the problem of change. Change is the process by which Being or the general essence realizes itself in particular things. The relationship of matter to form and of possibility to actuality is a relationship of development. Matter is the potentiality of the realization of the form. Being comes into existence through natural processes. What is realized when the potentiality of matter is completely developed into form is entelechy. This theory applies to all classes of changes, quantitative, qualitative, and local. All motion and alteration, origination and destruction are to be defined as the acualization of potentiality, the development of matter by form.

3. In turning from the process of change to the cause of change we are confronted with the same two factors, matter and form. Every motion[16] requires a moving cause, and since motion is a transition from one state into its opposite, it involves two principles, the mover and what is moved.[17] Now the thing moved is matter and the motive power is form. But neither one of these in itself is sufficient to produce motion; both must act together. Motion arises as the result of the operation of form on matter. The form is the operative principle and true cause of Becoming. But in addition to this

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[16] In general Aristotle uses motion and change as synonymous terms.

[17] Phys. V, 1. 224b, 26ff.

there is matter which acts as a retarding or detractive force preventing the perfect realization of the form.

Aristotle illustrates his doctrine of causes from two fields, biology and technology. In the former field the process of change is expressed in terms of growth; and in the latter field in terms of human activity. In the case of the technical arts, such as building, he distinguishes four types of causes, material, formal, efficient, and final.[18] For example, the final cause is the house as it exists in the mind of the architect, the formal cause is the blue-print, the material cause is the stone or wood from which the house is made, and the efficient cause is the laborer. In the case of organic processes, however, the formal cause constitutes both the efficient and the final cause, so that the four are reduced to two--material and formal.[19] The whole cosmic process is based upon these two causal agencies. The formal cause is teleological and represents purposive activity, while the material cause is mechanical and represents the blind activity of necessity. It is because of the resistance that matter offers to form that the forms fail to realize themselves completely in individual things. The degree of realization depends upon the capacity of matter to receive the forms. Because of its indeterminate possibilities matter

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[18] Phys. II,3.
[19] Phys. II,6.198a,25.

leads to accidental results, and in this sense it is the cause of the abnormalities and imperfections in nature.[20] Matter, then, is a secondary or accessory cause. In this doctrine of the two causes there is a manifest attempt, on the part of Aristotle, to recognize both the mechanical principle of Democritus and the teleology of Plato. The Aristotelian doctrine of the material cause represents the Democritean conception that an event is determined by what precedes it, while his doctrine of the formal cause represents the Platonic conception that an event is determined by what it develops into.

Every motion requires a moving cause, and this cause is the action of form on matter. But since every form may also be regarded as matter with respect to a higher form, a moving cause is also required for the form. The result is a series of formal causes which must culminate in a pure form that is not itself moved, but that is the cause of all motion.[21] Aristotle calls this pure form the prime mover and it is synonymous with God.[22] God is pure actuality, without any unrealized possibility, that is, pure form devoid of matter.[23] He is unchangeable in himself and hence immaterial,

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[20] Phys. II, 4ff.
[21] Met. Λ, 6. 1071b, 4.
[22] Phys. VIII, 5. 256b, 20.
[23] Met. Λ, 6. 1071b, 12.

because, according to Aristotle, only the immaterial can be unchangeable.[24] God is the source and condition of all change and causes motion in matter by being the object of desire, that is, by attracting matter from potentiality into actuality.

God, then, is both the efficient and final cause of all change. Everything that happens in the universe depends upon him. God sets the world in motion by first moving the outermost sphere of the heavens. Aristotle considers the universe as a system of concentric spheres of different diameters, in which the sun, moon and planets have their orbits. Each of these spheres imparts its motion to the next sphere within it, so that the motion of each is due to the action of the prime mover on the outermost sphere. All terrestrial changes are caused by the movement of the sun, and thus ultimately by the prime mover. The chief function of the deity, then, is to produce circular motion which is the most perfect motion and the nearest approach that the spheres can make to the unchanging spiritual life of the deity.[25]

4. Aristotle's natural philosophy deals chiefly with the problem of motion. In his Metaphysics he has given a general discussion of motion, but in his Physics he takes up this problem in its special phases. Natural science, according

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[24] Met. Λ,6.1071b,12.

[25] Met. Λ,7.1072a,20; Phys. VIII,6.ff.

to Aristotle, deals with the whole of corporeal existence, whose forms are actualized in their motions.[26] Nature includes the whole series of things which both cause motion and suffer motion. In all natural processes the material and formal principles are both active. The sum-total of natural existence, however, is determined by pure form which is itself unmoved.

Since the chief characteristic of nature is motion, a natural body is one that is capable of either motion or rest. In this respect natural bodies cannot be defined in mathematical terms, as Plato and Democritus had attempted to define them. A mathematical body is immovable, while a natural body is movable.[27] Furthermore, since natural bodies contain the principle of their own motion, they are to be distinguished from productions of art.[28] A natural thing has its own motive force within itself, but the original cause of this motion is the prime mover.

Aristotle's general definition of motion, namely, the actualization of potentiality, holds good for motion in all its various types. He discusses several kinds of motion; (1) increase or decrease in size, or quantitative motion; (2) transformation of one thing into another, or qualitative motion; (3) change of place, or local motion.[29] These

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[26] De Caelo, I, 1.
[27] Phys. II, 2. 193b, 31.
[28] Phys. II, 1. 192b, 13.
[29] Phys. I, 7; Gen. et Corr. I, 4.

correspond respectively to organic, chemical, and mechanical processes. The first two kinds of motion are based ultimately upon the third, namely, motion in space. Quantitative change consists of increase or decrease of matter and hence implies local motion.[30] Similarly, qualitative change is due to the local contact of the active and passive elements which produce the change and this contact implies local motion.[31]

Aristotle also mentions a fourth kind of change--origination and destruction, which he calls substantial change. Birth and decay in the absolute sense are impossible; "everything always comes to be comething and out of something."[32] It is only to particular objects, then, that these terms can be applied. When there is a change in the constitutive factors of an object, namely, in its form or matter, there is birth or decay, so that this type of change is to be distinguished from alteration or qualitative change. When the individual survives as a whole but its qualities alter, we have qualitative change; but when the individual begins or ceases to exist as a whole we have origination and destruction.[33] This type of change, however, always involves one of the three kinds of motion that we have mentioned above.

Aristotle continues his discussion of motion by taking up the questions of the Infinite, Space, Time, and the

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[30] Phys. VIII, 7.260a, 29; b, 13.
[31] Gen. et Corr. I, 5.
[32] Gen. et Corr. I, 3.317a 32.
[33] Gen. et Corr. I, 2.317a 30.

Continuity of motion. His conclusion with regard to Infinity is that it has potential but not actual existence. Number is capable of infinite addition, and extension is capable of infinite division, but this does not mean that there is an infinitely great number or an infinitely small particle, because the Infinite cannot be represented in actuality. Space is defined as the limit of the containing body at which it is in contact with the contained body.[35] Aristotle denies reality to empty space. Time is the measure of motion in respect to what is before and after.[36] Although space is finite, time is infinite. If time is infinite, motion must be eternal, because time is the number or measure of motion.[37]

The eternity of motion implies the continuity of motion because "what is always is continuous, whereas what is merely in succession is not continuous."[38] The next question is whether there can be any single movement of infinite duration, and Aristotle finds that only circular motion can meet this condition. This is the only kind of motion that continues in unbroken sequence without beginning or end. This eternal motion is effected by the prime mover.

5. Aristotle divides the universe into two parts, celestial and terrestrial. The former is characterized by

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[34] Phys. III, 6. 206a, 12ff.
[35] Phys. IV, 4. 212a, 20.
[36] Phys. IV, 11. 220a, 25.
[37] Phys. VIII, 1. 251b, 12.
[38] Phys. VIII, 6. 259a, 15.

the perfect circular motions of the heavenly bodies, and the latter by the imperfect rectilinear motions of terrestrial objects. The celestial realm is unchangeable, without beginning or end, and not subject to increase or diminution. The terrestrial realm, on the other hand, is subject to all types of change because of the strife of the elements. Aristotle considers the heavens as the seat of perfection and regularity and the earth as the seat of imperfection and change.

As contrasted with the circular motions of the heavens, the typical motion of the four elements, earth, air, fire and water, is rectilinear. This type of motion has opposite directions, upwards or downwards, toward the circumference or toward the center.[39] This implies the existence of absolute weight and lightness; the heavy tends downward and the light rises. Aristotle bases this theory upon the fact that matter of certain kinds tends to rise or sink in matter of other kinds, irrespective of bulk.[40] This means that there are qualitatively different kinds of matter, otherwise there could be no absolute weight. Differences in weight in the elemental bodies cannot be explained either by the pure extensive properties of the elements, as with Democritus, or by the theory of condensation or rarefaction

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[39] *De Caelo* I,2.268b,23ff.

[40] *Ibid.* IV,2.

of the older physicists.

The elemental bodies have natural tendencies to move in one direction or the other, and this corresponds to Aristotle's general theory of the realization of potentiality. "Motion of a body to its own place is motion to its own form." Now earth is absolutely heavy and has a tendency to move toward the center, while fire is absolutely light and moves toward the circumference. Water and air have only relative weight and water is heavier than air. So air moves above earth or water but below fire, while water moves above earth but below fire or air.[41] Each of these elements has a tendency to go to its own place. The natural position of the earth is the center of the universe, and then come water, air, and fire in succession. The rise and fall of these bodies is simply the actualization of potentiality.

In the De Generatione et Corruptione Aristotle discusses the four elements and their mixture in the production of things. He considers these elements as ultimate, unanalyzable entities; there is no body prior to them. Prime matter has no separate existence, but is found only as qualitatively determined in the elements. To account for the development of these elements Aristotle uses the fundamental opposites which had played such an important part in pre-Socratic philosophy. These opposites must be common to all perceptible

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[41] De Caelo, IV,4.311b ff.

things, and the only qualities that satisfy this condition are tangible qualities. These qualities can be reduced to four, warm and cold, and dry and moist. The first two are active and the last two are passive. The total possible number of combinations of these four qualities taken two at a time is six. But each combination must include an active and a passive quality; hence the combinations of hot and cold and of dry and moist must be excluded. This leaves only four combinations; hot and dry combine to form fire; hot and moist, air; cold and moist, water; and cold and dry, earth.[42] All of these primary elements are changeable and pass into one another in a cycle.

All composite bodies are made up of these four kinds of matter; they are the material causes of generation and destruction. By transmutation the elements can pass into one another and their mixture is the cause of the origin of all composite bodies. But this combination is not to be considered as a juxtaposition of the parts of one constituent with those of another. It cannot be a mosaic of small parts each of which retain their identity. It is not a mechanical mixture, as with Empedocles, but a chemical union--a thoroughgoing qualitative change. This change is brought about by the contact of the active and passive elements that produce the change.[43]

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[42] Gen. et Corr. II,3.
[43] Gen. et Corr. I,9-10.

Although local motion plays an important part in Aristotle's theory of change, a sharp distinction is to be noted at this point between the purely mechanical principle of Democritus and the Aristotelian theory of transformation. While Democritus had attempted to explain all change by the principle of the mechanical rearrangement of permanent particles differing only in shape, size, order and position, Aristotle finds that many purely physical occurrences must be conceived as modes of qualitative alteration or transmutation. Democritus had denied both the qualitative distinction between the elements, and the possibility of their chemical fusion, but the qualitative theory of Aristotle admits both of these facts. His definition of "becoming" as a realization of potentiality required him to include the phenomena of qualitative alteration as an important moment in his system. Quantitative relations, according to Aristotle, furnish only the occasions for qualitative changes. For the apparent changes of Democritus he substituted real change, and for the Democritan theory of interaction by pressure and impact, he substituted the theory of internal transformation. He considered the Democritan quantitative principle as only one factor in the process of change, since the mechanical motion which has its basis in matter appears only as a means to the actualization of the form. Consequently Aristotle accords as high degree of reality to the secondary as to the primary qualities.

6. Aristotle's great advance over Plato is that he defines the universal in such a way that it will explain Becoming. The sharp distinction that Plato drew between the universal and the particular, the Idea and the phenomenon, form and matter, failed to establish an adequate relationship between Being and Becoming. Aristotle retained the universal but he shifted its habitat and placed it in individual things where changes take place. Being a biologist rather than a mathematician, he was chiefly interested in the development of the form in the object. The forms are located in specific objects in so far as potentialities are realized in particular things. The field of potentiality is the locus of the form; the form actually resides in realized matter.

The process of growth, which Aristotle emphasized, represents a change that is not a departure from reality but an approach to reality. It is not a question of participation or departure, as with Plato, but of realization. True reality is the essence which unfolds in the phenomena themselves. Plato never explains the development of the form out of the germ, nor does he see the object as the potentiality of the form. From his standpoint the nature of the thing cannot be expressed in terms of the change; reality and change represent two separate fields. But Aristotle brings the change into the field of reality. For him, all change is a process going on in nature which represents the passage from potentiality to realization, and hence change expresses the

very nature of the thing itself. Change is a process in which reality is being realized. Reality is something which in its inmost essence is in process of development. Thus by establishing a relationship of development between matter and form, and by bringing the process of change into the world of reality, Aristotle solved the fundamental problem of Greek philosophy. The correlation between form and matter means that potentiality has the possibility of becoming actual, and this serves as an explanation of the whole process of change.

But this theory has its limitations. According to Aristotle, particular changes in individual things are due to the fact that each thing has its own special form which acts as a creative force. A question arises here as to the relationship between these particular forms and the highest form or God. The only influence that Aristotle attributes to the prime mover is to cause a circular motion in the outermost sphere of the universe. But it is impossible to derive the great variety of motions in the world from this one simple activity. The principle of one general motion is insufficient to account for special motions. There is a gap here between the individual forms as causes of special motions, and the highest form as the cause of general motion.

Moreover, Aristotle does not utilize change to account for the origin of forms, but only for the realization of forms. His whole theory of change is based upon the assumption of the prior existence of forms which can be actualized

in things. With regard to the question of the rise of forms, the Aristotelian statement closes the door to evolution. It makes impossible the origination of a form or a species out of the process of change. Change, for Aristotle, cannot be a function of the appearance of the form; the form must have existed prior to the change or change would be impossible. Aristotle assumes the prior existence of species before he can account for development within that species. The germ of a lion will develop into a lion, and the germ of an oak into an oak, but the species lion and oak must have existed in advance of the development; they are implied in the potentiality of the germs. Evolution, then, according to Aristotle, must take place within the species; it cannot be a general doctrine that will account for the origin of the species. This is the great distinction between the theory of Aristotle and that of modern biology. Not until Darwin do we get a real explanation of how the form arises out of the process. With Darwin each form is the result of living in a certain environment under certain conditions. Natural selection, variation, etc. develop forms that have not previously existed. Modern evolution presents a process out of which the forms or species arise, but for Aristotle these forms must always have been there.

CHAPTER VII

AN EVALUATION OF THE GREEK THEORIES OF CHANGE IN THE LIGHT OF MODERN SCIENCE

1. The scientific method of the Greeks was directed toward a knowledge of unchangeable Being. Democritus found the object of true knowledge only in the immutable atoms, and regarded changeable phenomena as the objects of confused or obscure thought. Plato sought in sensuous objects only the suggestions of the ideal static forms which the soul had once beheld in a previous stage of its existence. Aristotle considered the object as the realization of the form or universal essence, and hence his analysis was calculated to discover those universal, general characters by which the form is defined. The goal of ancient science was the universal forms which could be completely defined in themselves, and by means of which different instances of the same thing could be identified. Ancient science, however, proved deficient in invention and discovery. Its aim was to grasp the universals which held all things together, but it lacked an apparatus for changing the universals with which it dealt.

In the ancient world there was no distinction between the technique of the scientist and that of the philosopher,

because the ancient scientist did not have to appeal to any experimental test. This was due to the fact that the experience of the individual as a single self did not count. Personality, like the Platonic Idea, was a type. The individual could not use his experiences to build up, but only to tear down, and subjectivism became tantamount to skepticism. Greek personality was not functional; it could not turn back on the situation and reconstruct things. In so far as the individual was hostile to the existing order, his experiences were considered simply as anomalies and ignored.

But in modern times experience can be stated in terms of the self as an individual and not as a type. Modern personality is functional, and modern science can utilize the experiences of the individual to reconstruct its world. In the experience of the individual an exception arises which does not fit in with the existing theories. The exceptional instance leads to the formulation of an hypothesis. The hypothesis is then submitted to an experimental test, and if it works the theory is accepted. In this manner the laws of modern physical science have been formulated.[1]

The modern scientific method, then, does not attempt to acquire a knowledge of the unchangeable, but to determine the nature of the actual world as it changes from moment to moment. Modern science is concerned with studying a process

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[1] Cf. George H. Mead, "Scientific Method and Individual Thinker," Creative Intelligence, p. 176ff.

rather than with contemplating the universal forms that lie behind the process. Hence modern science is occupied with data or facts rather than with universal essences. This shift in emphasis from universal essences and static forms to the changing processes of the sensible world, and the application of mathematical principles to this sensible manifold, lead to a prediction and control of events which Greek science never attained. These facts will become more evident as we compare the three great Greek theories, those of Plato, Aristotle, and Democritus, with the salient developments of modern science, with reference to the problem of change.

2. Plato regarded the physical world as unreal because it was the scene of incessant change. In his theory there is a constant retreat from the world of experience which is physical and changing to the world of reality which is logical and changeless. This emphasis upon unobservable ideal forms leads to a depreciation of the observable world of sensation. When conceptual theories become more important than observable facts, attention is transferred from the world of experience to the world of forms. This fact is partially responsible for the decline of the scientific spirit during the Middle Ages.

Reality, for Plato, is made up of ideal mathematical forms which only reason can grasp, rather than physical objects which can be observed. The function of knowledge, then, is to get away from the fleeting world of sense to the fixed

realm of universals. The method by which this knowledge of reality is attained is a mathematical method. Now, in emphasizing the importance of mathematics in scientific investigations, Plato is in accord with the procedure of modern science. But the chief aim of Plato's mathematical method was to reach true Being, the fixed forms that lie behing the changing, sensible manifold. He applied his mathematics to static situations rather than to processes, and consequently he could not deal with the world of experience and get to the inside of changes as they are taking place. The absence of an infinitesimal method prevented him from bringing reality into change in the form of mathematical laws which describe processes and make possible the prediction of future events. The only motions which he recognized as representing reality were the typical motions of the heavenly bodies, which, according to the Greek assumption, moved with uniform velocities in circular orbits. Plato had no apparatus, however, for dealing with changing changes, such as are found in the phenomena of acceleration and deceleration.

Modern science has transferred the object of knowledge from the realm of Being to that of Becoming, and has carried the mathematical method over into the field of change. The physical world, bound by the chains of mathematical analysis, is the real world. We can now get a mathematical statement of those things which Plato regarded as lying outside the world of reality. The differential calculus enables the

modern scientist to analyze a change into a set of smaller units that are additive, and thus to get a mathematical formulation for a changing change as that change is in the actual process of occurrence at a particular instant. In this way modern science brings a permanent element of reality into change in the form of a law which expresses a changing change taken at an instant, but without stopping the process at that instant. The following simple illustration will serve to show how the differential calculus enables us to determine the rate of change of a variable quantity.

Suppose that a feed pipe is pouring water into a conical tank at the rate of one cubic-foot per second. At the base of the cone the water will rise very fast, but as the volume of water increases the rate at which the level rises will decrease. The problem is to determine the rate at which the level rises at any instant.

Let y be the depth of the water in the cone after the water has been flowing in for t seconds. In order to simplify the problem, suppose the cone is so constructed that the volume of water at any instant is represented by the cube of the height, that is y^3. But at the end of t seconds t cubic-feet of water have entered the tank. Hence $y^3=t$; and $y=t^{1/3}$.

It is just at this point that the method of differentiation becomes of use. The rate of change of y is expressed by the derivative of y with respect to t, that is, by dy/dt. This is a method of determining the limit of the ratio of an

infinitely small increment of height to an infinitely small increment of time, as the increment of time approaches zero. The rate at which the level of water rises at any instant t will be represented by the derivative of y at that instant, that is, by dy/dt.

Since $y=t^{1/3}$, then by applying the device of finding a derivative, which consists in multiplying the coefficient by the exponent and reducing the exponent by one, we have, $dy/dt = \frac{t^{-2/3}}{3} = \frac{1}{3t^{2/3}}$. If we select 8 as a value for t, the water level is rising at the rate of 1/12 feet per second at the end of the eighth second.

In this way it is possible to get an expression for a changing change taken at an instant, but still representing that instant as in a process of change. By this method one of the fundamental limitations of Greek science was overcome.

3. In contrast with Plato, Aristotle localized the forms in individual objects and hence regarded the phenomenal world as the real world. As a result, attention was directed away from the mathematical method toward the empirical method, especially in the field of biology. However, Aristotle localized the forms in individual objects and hence regarded the phenomenal world as the real world. As a result, attention was directed away from the mathematical method toward the empirical method, especially in the field of biology. However, Aristotle could not utilize the experiences of the individual observer for purposes of reconstruction, but only to arrive

at the forms or class concepts. The function of science, according to Aristotle, is to enable one to grasp the thing in terms of its essential characters, that is, in terms of the forms or universals. These forms are the common attributes which can be observed in the same kind of things and which enable us to classify such things in terms of genera and species. These general ideas, however, find their expression only in individual objects. So the purpose of observation is to recognize the form in the individual, and thus by means of the individual to arrive at the universal. It is the universals which make particulars the class or kind of existence which they are.

The defect of such a method is that characters cannot be isolated from the object and studied by themselves. This point is very well illustrated in the Aristotelian theory of motion. He regarded motion as an essential quality of the object--something which could not be defined apart from the essence of the object in motion. This theory is based upon the assumption that every object has its natural motion, to its own place, in a straight line. Since Aristotle considered change as the realization of potentiality, motion, which is a form of change, could not be regarded as something that is opposed to reality; it had to belong to the essential nature of the thing. And when change is found in the thing, it can only be studied from the standpoint of the nature of that thing. In such a procedure there is no method for studying

the process of change by itself and discovering laws of change in contradistinction to the formal causes of change.

One of the great innovations of Renaissance science was the isolation of the conception of motion. Galileo abstracted motion from the nature of the object and set it up as something that could be studied by itself apart from the thing that is moving. This study of motion as a separate phenomenon led Galileo to the discovery of the laws of motion. By actual experiments performed from the tower of Pisa, he showed that, save for a slight difference produced by the resistance of the air, heavy bodies and light ones fall at the same rate of speed. This proved that velocity is not proportional to weight, but to time; $v=s/t$. Thus, by isolating the conception of motion, Galileo was able to formulate a general law which holds good for all moving objects.

When weight was discarded as a determinant of velocity it was necessary to get a new unit by which to identify objects that change. Galileo defined this new unit as mass, and identified it as the permanent element that constitutes the central reality of the thing. This marks a great advance over the Aristotelian theory. With Aristotle mass had been considered as synonymous with weight and as a quality of the object. But the modern world defines mass in terms of inertia. Inertia is the "persistence of matter in its state of either rest or motion, and its resistance to any attempt to change that state." It is the only property inherent in

matter which has to do with motion. This distinction between mass and weight is very important, because weight is dependent on gravity while mass is not. A meteoric body would weigh about twenty-eight times as much at the surface of the sun as at the surface of the earth, and at the center of the earth it would weigh nothing, but its mass would always be the same. Modern science put reality into matter in terms of mass, whereas for Aristotle matter had been only a potentiality. Both mass and motion, in modern physics, are treated as concrete realities, and as realities that are capable of measurement.

Along with the doctrine of inertia Galileo introduced a new conception of force, which proved to be a startling innovation in science. Aristotle had defined force as that which produces motion or velocity, but Galileo showed that it was that which produces a change of velocity, that is, an acceleration. A body that is not acted upon by any external force will either remain at rest or move in a straight line at a uniform velocity forever. Hence any external force that affects the status of the body must do so by producing a change of velocity, that is, an acceleration. If force were something that caused motion, as with Aristotle, then a moving body would come to rest with the cessation of the application of the force, but as a matter of fact it simply ceases to change its velocity.

Galileo first studied the phenomenon of acceleration in the swing of the pendulum, and then by letting a ball roll down an inclined plane. He noticed here, not a ratio of space to time, as in the case of velocity, but a ratio of velocity to time, that is, the ratio of a length of space to the second power of a time. This conception of acceleration is the foundation stone of the Galilean and Newtonian mechanics. The mathematical expression of this phenomenon could not be perfected, however, until the discovery of the calculus by Newton and Leibniz.

The phenomenon of acceleration did not present itself to the Greeks as a field in which reality could be found, because they had no mathematical technique which would enable them to express a changing change. Their ideal of proportion and harmony led them to derive their analysis of motion from the study of astronomy, because the heavenly bodies, according to their assumption, move with uniform velocities in circular orbits that are perfect in their form and their relationships. The only motion to which they could apply their mathematics was uniform motion; they had no method of formulating a law that would express an acceleration.

4. Of the three theories that we are considering in this chapter, namely, the Platonic, the Aristotelian, and the Democritan, the last is most in accord with modern scientific conceptions. Democritus, in his physical theory, reduced all changes to the movements of atoms in space. He held the

principle that the sole object which a true knowledge of nature can deal with is that which is capable of quantitative determination. In a fashion quite similar to this, Renaissance science formulated its knowledge of things in terms of the motions of bodies. All knowledge consists in tracing back what is perceived to the motions of bodies in space.

Descartes paved the way for the modern quantitative theory by giving a mechanical statement of the spatio-temporal world. He identified matter with space and held that the world of extension is a geometric universe, a vast machine operating according to mechanical laws. Moreover, according to Descartes, this mechanical universe, consisting of matter and motion, can be expressed in mathematical terms. There is, he believed, a logical structure to the universe which corresponds to the structure of thought. This is illustrated very clearly in his analytic geometry in which the algebraic equations answer to the realm of thought and the conic sections which these equations represent, answer to the world of extension. The equation for a circle, e.g., is $x^2 + y^2 = r^2$, where x and y represent the coordinates of a point on the circle and r the radius. The circle itself is a geometric extended figure, and the equation by which it is represented is a conception of the mind, but there is an exact correspondence between the two.

In so far as the theory of Descartes is quantitative in its method it agrees very closely with that of Democritus.

Both expressed matter in terms of extension and both referred all changes back to a quantitative basis. But in any mechanical statement of the universe the question arises as to how to dispose of the secondary qualities and at this point the theories of Democritus and Descartes diverge. For Democritus the real ultimates are atoms and the void. But a knowledge of these cannot be obtained in sensation because they are imperceptible to the senses. Hence sensation does not truly represent the nature of perceived things. Democritus, then, considered the secondary qualities as obscure or confused thought and hence as abnormalities. He regarded them as perturbations of the soul and thus robbed the world of its values because these perturbations are of no cosmical importance.

But Descartes did not find it necessary to rob the world of its meaning and to regard the spiritual values as perturbations, as did Democritus. The soul, for him, proved a convenient locus in which to place all of those characters which could not be accounted for by purely mechanical principles. So instead of pure mechanism, as with Democritus, the theory of Descartes represents a dual aspect of mechanism and idealism. The universe could be stated mechanically and still leave the values in the soul as something which had cosmical importance. The conception of the soul as a habitat for the values of the world fortified the position of the modern mechanical theory. If the whole qualitative side of experience can be placed in the soul, this leaves physical science free

to deal with the quantitative side.

A second deficiency in the Democritan theory is the fact that he never succeeded in formulating a law which would describe the motions of his atoms. He made out of change a purely arbitrary affair without getting any statement of the process itself, and the only permanent factor was the permanence of Being. One of the striking features of early modern science was that it transferred the object of knowledge from the realm of Being to the realm of Becoming. It concentrated its efforts upon finding laws of change, and in so far as it could arrive at these laws it was able to bring a permanent element into the very process of change itself, something which the Greeks could never do. Democritus had applied his quantitative principle only to Being. But when Newton, in accordance with the principles of modern mechanics, gave the mathematical theory for the explanation of Kepler's laws, he applied the quantitative principle to Becoming or change in nature instead of to Being.

Newton formulated a law of universal attraction by means of which he could state the motions of heavenly bodies in the same terms as Galileo had stated the motions of earthly bodies. He demonstrated mathematically that the physical conceptions by which Galileo had accounted for the fall of an apple to the ground, could also be applied to the motions of the whole astronomical system. This law of attraction states that every portion of matter attracts every other

portion and that the stress between them is proportional to the product of their masses and inversely proportional to the square of the distance between them. Here we have a uniformity that includes an infinite diversity, inasmuch as the changes in any body must be stated in terms of all the other bodies of that system. Such a law as this gives a quantitative statement which can be applied, not only to matter, as in the theory of Democritus, but also to motions. Newton had the same atoms as Democritus, but atoms which he expressed in terms of inertia. The quantitative theory of Democritus pertained only to matter and hence the only permanence he could get was a permanence of Being. But in the Newtonian theory permanence is brought into the very change itself by way of a law of change. The law which comprehends the various phases of change serves to represent the constant character of the thing that persists throughout the change. The world necessarily appeared to the early philosophers as a scene of arbitrary change, because they had no mathematical methods which would enable them to quantify physical processes. But change reduced to law takes on reality and no longer appears as a mystery.

The attempt of the Greek Atomists to reduce all qualitative changes to a quantitative basis is the same, in principle, as in modern science. The Democritan atoms, however, have been broken up by modern physical science into smaller units. These units, called electrons, consist of

the negative particles which revolve around the central nucleus of the atom. These electrons are identical units, and the qualitative differences in things are explained by their number and arrangement, and the size of the central nucleus. Qualitative changes are now referred to the configurations and motions of these identical units acting together in a system. In these respects modern science has taken over the fundamental principle of ancient atomism, although it has extended and refined that principle.

5. The method of modern science is the application of mathematical principles to physical processes. The technique involved in this method is the reduction of all phenomena to certain fundamental identical units, such as units of mass or units of force, which can be stated in the form of mathematical equations. In this way it becomes possible to quantify and measure all changes that are taking place. Greek science was decidedly deficient in this respect; it could never get identical units with which to quantify changes. Democritus, who came nearest to the modern method, had a quantitative theory of matter which was metaphysical rather than physical. He never attempted to quantify change, and even in the case of matter he had no permanent standard of measurement.

The logical principle involved in the quantitative, mathematical method is the principle of identity, and the classic formulation of this principle is found in the

philosophy of Leibniz. Identity as a basis for intelligibility forms the keynote of the whole Leibnizian philosophy. Confronted with the problem of reconciling unity with difference, Leibniz devised a system of ultimate elements, called monads, in which the meaning of every element must be stated in terms of the whole. Each monad has the same content, and expresses the entire universe if all of its implications are carried out. Any particular part in isolation is a reduction of the whole; the whole universe is potentially present and seeks its realization in each particular element.

And yet there are differences from the point of view of perspective. Although each monad has the universe for its content, it maintains its own individuality. There is an infinite number of these individuals each distinct from the other, because each represents the universe in a different degree of intensity. The monad in its form is individual, but its content is the substance of the universe. Here we have the principle of identity in the metaphysical sense that the content of all the monads is identical. This identity is that of the part with the whole; everything is in anything.

The Greek atomism had been forced to establish the reality of the parts at the expense of the whole. This was due to the fact that those atoms had only external variety with no internal relation to the world. But Leibniz solves this difficulty by assigning an internal variety to his monads, and by means of an intensive relation the whole and

the part can be brought together. Each part contains the whole within itself potentially by means of representation.

The monad has the power of unfolding its whole nature from within itself. Change, then, must be considered as the unfolding of the whole which the monad potentially represents. There is change from one state of representation to another. But throughout all changes each monad manifests the whole universe as its own internal content. So all change takes place within the identity or permanence of a simple substance. With this theory Leibniz reconciles the problem of permanence and change which had caused such a dilemma in Greek philosophy. The content of the monads is identical, but their forms change.

The significance of Leibniz' theory for physical science lies in the fact that he regarded his ultimate elements as "force-substances." He gave up the old idea of substance as the unchangeable substratum of changing states and defined it in terms of force. At the same time change took on the meaning of activity or work. The essential nature of bodies, then, is not extension or mass, but force, that is, the capacity to do work, and this ultimate substance conserves the same content in all of the changes that are going on. Leibniz was led to his doctrine of the vis viva by the mechanical problem of inertia. The energy theory is simply an expansion of the Newtonian physics to include, not only the motions of bodies, but also other processes, such as changes in heat, electricity, etc. Subsequent experiments

have determined an equivalence between thermal, mechanical, chemical, magnetic, and electrical energy, and this equivalence has served to prove the truth of Leibniz' theory that there is something having the capacity to do work, which remains identical with itself during all transformations.

The introduction of the energy theory led to the law of the conservation of energy which asserts that the quantity of energy in the universe is fixed and invariable. The doctrine that energy is neither created nor destroyed in its transformations was finally demonstrated by Mayer. Joule put it on a sound quantitative basis by determining the mechanical equivalent of heat, which proves that heat and energy are of the same nature and that all other forms of energy can be transformed into an equivalent amount of heat.

In the mobility of phenomena, then, there is one constant element--energy. True reality is the force which is the cause of change and which remains constant even though changes cease. This conception of energy has replaced the old idea of matter as the substratum for all changes. Like the true Being of the Greeks it is eternal, indestructible and constant in quantity. And throughout all its transformations it remains as an element identical with itself. This is the most adequate solution of the problem of permanence and change that has yet appeared, and one that presents the most striking contrast between the Greek and the modern treatment of this problem.

Under whatever form energy appears it can be reduced to quantitative terms and measured by the quantity of the effect that it produces, namely, work. The units in terms of which work is measured are the foot-poind, kilogram meter, erg, and joule. Energy thus becomes a unitary system of reference on which to base measurement. By means of the concept of work the different series of physical processes, such as heat, motion, electricity, magnetism and chemical attraction are correlated in an inclusive system and related to a common denominator. In this way all physical processes become homogeneous and can be reduced to numerical differences of quantities of work. This permits a numerical determination of any particular process and its comparison with any other process. A unit of work is the common standard of measurement, the identical unit that applies to all processes in general.[2]

In this respect the Greek theories of change were very inadequate. Even atomism, which is nearest akin to the modern scientific statement, failed to express the process of change in terms of measurable identities. The atoms were conceived as metaphysical characters rather than as something capable of measurement. Modern physics, however, in reducing all changes to identities either of matter or of motion or of energy, to which a standard of measurement can be applied,

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[2]Cf. Cassirir, Substanzbegriff und Funktionsbegriff, pp. 249-270.

brings permanence into the very change itself. It is this ability to express the process of change in terms of some permanent standard of measurement that marks the culminating distinction between the modern physical science and that of the Greeks.

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